P1.10 ONGOING JAPANESE LONG-TERM REANALYSIS PROJECT (JRA-25); ASSIMILATION OF NOAA POLAR-ORBITER SATELLITE SOUNDER DATA

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1. INTRODUCTION

To support operational climate monitoring and dynamic seasonal forecasts, a long-term reanalysis dataset, which is consistent with operational quasi-real-time climate analysis system, is required. A Japanese reanalysis project named JRA-25 was launched in 2001. It started as a 5-year cooperative research project between Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Power Industry (CRIEPI), and the target period is from 1979 to 2004. JMA's operational global spectral forecast model and 3 Dimensional VARiational techniques (3DVAR) are adopted, some kinds of observations and dataset for most of boundary conditions are firstly introduced into the long-term reanalysis.

On the other hand, JMA has never experienced operational assimilation for Brightness Temperature (or equivalent Temperature of Black Body; TBB) data derived from non-advanced TIROS Operational Vertical Sounders (TOVS) on board up to NOAA-14.

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Not only to achieve more accurate assimilation, but also to avoid artificial discontinuity caused by changes in the retrieval schemes, effective quality control schemes and a direct assimilation method for TOVS TBB have been developed.

In this short paper, the status of the JRA-25 project is presented with emphasis on the TOVS direct assimilation, its quality controls and its performance. Detailed information of the project can be found in our web site, http://www.jreap.org/index-e.html.

2. GENERAL STATUS OF JRA-25

For JRA-25 project, the supercomputer FUJISTU VPP5000/32PE in CRIEPI is offered as the main computational resource. Data production is divided into two sequences (1979 - 1990: Stream-B, 1991 - 2004: Stream-A). After 2004, the data production will be yielded to JMA operational Japanese Climate Data Analysis System (JCDAS), which will employ almost the same system as JRA-25.

The systems, observations, and boundary datasets used are briefly described below.

FORECAST AND ANALYSIS SYSTEM

Vertical Resolution:

40 Layers with the top level at 0.4 hPa.

Horizontal Resolution:

Spectral Triangular-truncation at total wave-number 106. (T106; equivalent to about 110 km grid length)

Forecast Model:

JMA operational Global Spectral Model (GSM).

Atmospheric Assimilation Scheme:

Modified JMA operational 3DVAR (6 hourly)

Land surface analysis system:

JMA simple biosphere model (daily).

Snow depth analysis system:

Modified JMA operational 2-dimensional optimized interpolation scheme (daily)

OBSERVATIONS

(1) Conventional Observation:

Conventional observation data used in for ERA-40 (1957 - 2002) was provided by European Centre for Medium-Rage Weather Forecasts (ECMWF), including Atmospheric Motion Vectors (AMV) for METEOSATs reprocessed by EUropean METeorological SATellites organisation (EUMETSAT). The observation data accumulated in JMA are added from 1989 onward.

(2) TOVS / Advanced TOVS(ATOVS) level-1c:

TOVS/ATOVS level-1c data from 1978 to 2003 used for raw data assimilation in ERA-40, was also provided by ECMWF with their checklists. (Hereafter, level-1c means earth located brightness temperature, issued by each instrument.)

(3) SSM/I observation:

Special Sensor Microwave / Imager (SSM/I) data from 1987 to present are provided by National Climatic Data Center (NCDC) and the Comprehensive Large Array-data Stewardship System (CLASS) of National Oceanic and Atmospheric Administration (NOAA). Snow coverage and precipitable water vapor data are retrieved and assimilated. Sea-ice is also re-analyzed with SSM/I observation.

(4) AMV of GMS-3 to 5:

The Meteorological Satellite Center (MSC) of JMA processed GMS's AMV from 1987 to present on the basis of EUMETSAT's retrieving algorithm. Those are substituted for Cloud Motion Wind (CMW), which have been operationally processed.

(5) Chinese snow depth:

Meteorological Research Institute (MRI) of JMA digitized daily snow depth observation data over Chinese terrestrial area (1978 - 2003) from "Monthly Report on Chinese Ground Meteorology" published by China Meteorological Administration (CMA).

(6) Tropical Cyclones (TC) wind retrieval:

An estimation method for wind around TC has been developed by Dr. Michael Fiorino of Lawrence Livermore National Laboratory (LLNL). Those data are found to be very effective for improving meteorological expressions of TC. This is the first time these TC wind retrieval data have been introduced into a long-term reanalysis.

OTHER BOUNDARY DATASET

(1) Sea Surface Temperature (SST) and sea-ice:

JMA has achieved the Centennial in-situ Observation-Based Estimates of variability in SST and marine-meteorological variabilities (COBE) project. The daily SST and sea-ice concentration data by this project are adopted as the boundary conditions.

(2) Historical 3-dimensional Ozone concentration:

MRI and the Atmospheric Environment Division (AED) of JMA analyzed historical ozone concentration data (1978 - present) with a Chemical Transport Model (CTM) using total column ozone observation by Total Ozone Mapping Spectrometer (TOMS) project.

(3) Snow coverage:

Snow coverage distribution with horizontal resolution of 0.25 x 0.25 degree is retrieved from SSM/I observation, and used in the snow analysis system. In the periods when no SSM/I observation is available, the weekly snow coverage analyzed by the Climate Prediction Center (CPC) of NOAA/National Centers for Environmental Prediction (NCEP) has been used with daily interpolation.

3. TOVS DATA PREPARATION

In our quality control scheme, data from High Resolution Infrared Radiation Sounder (HIRS) and Microwave Sounding Unit (MSU) of TOVS are coupled together as level-1d, because HIRS and MSU observations should be compared with each other and examined their consistency. (From now on, level-1d means earth-located brightness temperature data, in which observations from multiple instruments are coupled in the same position.) Only Stratospheric Sounding Unit (SSU) observation is used independently as level-1c data, because only SSU data are rarely under the influence of complicated tropospheric conditions and weighting functions of its channels are rather isolated from others.

Combined HIRS and MSU data (level-1d) are created with a nearest neighbor method. Generally, HIRS data located at the nearest Instant Field Of View (IFOV) to the center of MSU IFOV are selected. The average and standard deviation values for HIRS channel-8 TBB in each MSU IFOV are also prepared to diagnose the homogeneity of cloud contamination.

4. TOVS QUALITY MONITORING

ECMWF made their error check lists (so-called blacklists) available, which was tailored for ERA-40 as a result of their quality monitoring effort (Hernandez et al., 2004). We also refer to other quality information such as the operational status information of NOAA satellites posted by NCDC (see http://www2.ncdc.noaa.gov/docs/podug/html/app-d.htm). In addition, we have been struggling to accomplish our own quality monitoring of TOVS. So far we have found that almost all types of errors can be classified into the following 6 types.

(1) Bad Allocation:

Spots existing around the orbit might have incorrect location that can be detected by comparing with other spots in the same or the neighbor lines.

(2) Worse Location Error:

In some cases, spots might have apparently wrong allocation.

(3) Periodical Calibration Error :

Some parts of erroneous brightness temperature may come from incorrect information for calibration.

(4) Relatively High Noise:

Considerable parts of HIRS data are contaminated by relatively high noise.

(5) One Spot Observation Error:

A spot might have incredible high or low TBB abruptly.

(6) Line Observation Error:

All at once, every spot in a line has obviously different TBB from other lines' ones.

We developed originally applications for quality controls with regard to the types of errors (1) to (4). Considerable parts of errors are removed, and we have been creating our original, more precise checklists (JRA-25 TOVS error lists).

	Channel	Center of weighting function	Acceptable condition	Absorption material
HIRS	2	60hPa		CO_2
	3	100hPa		CO_2
	4	400hPa	clear, over sea	CO_2
	5	600hPa	clear, over sea	CO_2
	6	800hPa	clear, over sea	CO_2
	7	950hPa	clear, over sea	CO_2
	10	900hPa	clear, over sea	H_2O
	11	700hPa	clear, over sea	H_2O
	12	500hPa	clear, over sea	H_2O
	15	700hPa	clear, over sea	CO_2/N_2O
MSU	2	700hPa	clear, over sea	O_2
	3	300hPa	clear, over sea	O_2
	4	90hPa		O_2
SSU	1	15.0hPa		CO_2
	2	4.0hPa		CO_2
	3	1.5hPa		CO_2

Table1 Assimilated channels

5. QUALITY CONTROL AND ASSIMILATION METHODS FOR TOVS TBB

To optimize selection of channels, land/sea occupation rate for each IFOV are calculated. If a spot is over land or around a shore area (within 150km from coastline), the tropospheric channels (see Table1) are not used because of uncertainty in surface emission. As it is also difficult to distinct influence caused by the tropospheric conditions from inhomogeneity in each IFOV, data with MSU IFOV position 1, 2, 10, and 11 (limb scan data) are rejected.

To identify weather conditions and surface emission, surface temperature over sea area is obtained by interpolating SST. Evaluations for weather condition are carried out according to the following conditions (Reale, 2001; McMillin and Dean, 1982).

CONDITIONS FOR CLEAR SPOTS:

For daytime observation,

(HIRS ch18) - (HIRS ch8) < or = 10.00 K.

For night-time observation,

(HIRS ch18) - (HIRS ch8) < or = 2.00 K,
(HIRS ch8) - (HIRS ch18) < or = 4.00 K,
(HIRS ch19) - (HIRS ch18) < or = 2.00 K,
and (HIRS ch18) - (HIRS ch19) < or = 4.00 K.
Here (HIRS ch8), (HIRS ch18), and (HIRS ch19) are brightness temperatures of HIRS channel 8, 18, and 19 respectively.

To select reliable tropospheric observation, we choose only the spots that have the smallest 15% differences between HIRS channel-8 TB and estimation with forecast and radiative transfer model (Wylie and Menzel,1999). We also reject observations of tropospheric channels in higher latitude (higher than or equal to 50degree for the both hemispheric summers, and higher than or equal to 40degree for winters.), because of the difficulty in finding accurate clear condition. Therefore, the tropospheric observations in very restricted cases, which are in ideal, clear conditions over the ocean, are assimilated.

Regarding to the stratosphere temperature, we found large scale horizontal distortion in the experimental stage of assimilation. Especially when a single spacecraft of stratospheric observation is available, obvious 12 hourly oscillation of temperature is found around and above the tropopause (Fig1(b)). This unnatural behavior of temperature is supposed to be caused mainly by biases of the forecast and the spatially limited coverage of observation. When the observations of stratospheric channels don't distribute uniformly, the compensatory analysis increment appears in the sparse observation area to keep its horizontal consistency. To avoid such unrealistic fluctuations with expanding coverage of observation, the time window for the stratospheric observations of TOVS is extended up to 12 hours. In order to preserve shorter time-scale phenomenon such as diurnal oscillation, observations outside of the 6-hour time window are thinned more sparsely than inside.

The differences between TBBs and the optimal solutions of One Dimensional VARiational method (1DVAR) are accumulated to make our automatic bias correction. They are classified into each IFOV position (HIRS: 1 - 56, SSU: 1 - 8) and each TBB class. Values for bias correction are gradually updated in each assimilation step with considering the average departures.

Most of procedures in TOVS assimilation and quality control were generally developed on the basis of those of JMA operational ATOVS assimilation. The calculations for radiative transfer involved in those procedures are performed with the fast radiative transfer model RTTOV-6 (Saunders et al., 1999). At the beginning of quality control, TBBs of each channel are compared with the profiles in the forecast. Then 1DVAR is performed to check the consistency of each spot observation, although its optimal solutions are not used in the 3DVAR assimilation. (Okamoto et al.)

6. PERFORMANCE OF JRA-25

As far as we could see, JRA-25 has the following advantages and drawbacks.

FAVORABLE POINTS

(1) Rational consistency in and around the periods of volcanic eruptions

Historical global mean precipitation in ERA-40 and JRA-25 are shown in Figure 2. Reanalyses except for

JRA-25 have considerable distortion around volcanic eruptions, such as Pinatubo's started on 15 June '91, and El Chichon's started on 29 March '82. JRA-25 seems to have rather consistent sequences around those periods. We believe so far that those apparent discontinuities came from those aerosols (volcanic ash) affected remote sensing data, which are especially influential in visible and infrared observations. We have strictly confined conditions of the tropospheric channels to use, and have avoided that contamination to a certain extent.

(2) Reasonable distribution of precipitation

Fig 3 shows monthly precipitation of JRA-25 and ERA-40, with their departure from the CPC Merged Analysis of Precipitation (CMAP) data. Precipitation distribution particularly around the tropics of JRA-25 shows more reasonable agreement with CMAP data, even when it is compared with ERA-40's.

UNFAVORABLE POINTS

(1) Too sensitive to both data absence and quality change of TOVS

Fig 4 shows historical global mean temperatures at 100hPa of JRA-25, ERA-40, and NCEP/NCAR reanalysis. In February 1980, when only NOAA-6 observation was available, disagreement between observation of HIRS channel-3 and MSU channel-4 resulted in serious distortion of the time series of JRA-25. On the other hand, there are considerable jumps in other reanalyses, which seem to be caused by artificial errors. Therefore it is important to compare reanalyses each other to detect their possible errors.

(2) Relatively low reliability of the performance in the upper stratosphere.

Fig 5 shows time series of the global mean temperature increment of assimilation. Relatively large increments are found in the upper stratosphere. Taking substantial disagreement between JRA-25 and ERA-40 into account, our forecast and assimilation are not going so well regarding to those layers.

7. SUMMARY

We are challenging the original reanalysis project using new observations for snow-coverage, SST, TC winds, and so forth. So far the progress of data production is satisfactory. We have made special efforts to develop simple but effective TOVS quality control and assimilation procedure and to create precise TOVS error lists. Although we have already found some problems to be fixed, the strict quality control procedures have brought us rational consistency around the volcanic eruption periods.

8. ACKNOWLEDGEMENTS

Authors would appreciate the international cooperation for JRA-25 project. ECMWF provided conventional and TOVS/ATOVS data used in ERA-40, SSM/I raw data were provided from NCDC/NOAA and CLASS/NOAA, TC retrieval winds from Dr. Fiorino in LLNL, METEOSAT reprocess AMV from EUMETSAT, CPC snow coverage analysis and NCEP/NCAR observations from NCEP/NOAA. We would also thank all reanalyses communities and pioneers for their valuable supports and advices. All those contributions make our project surely successful.

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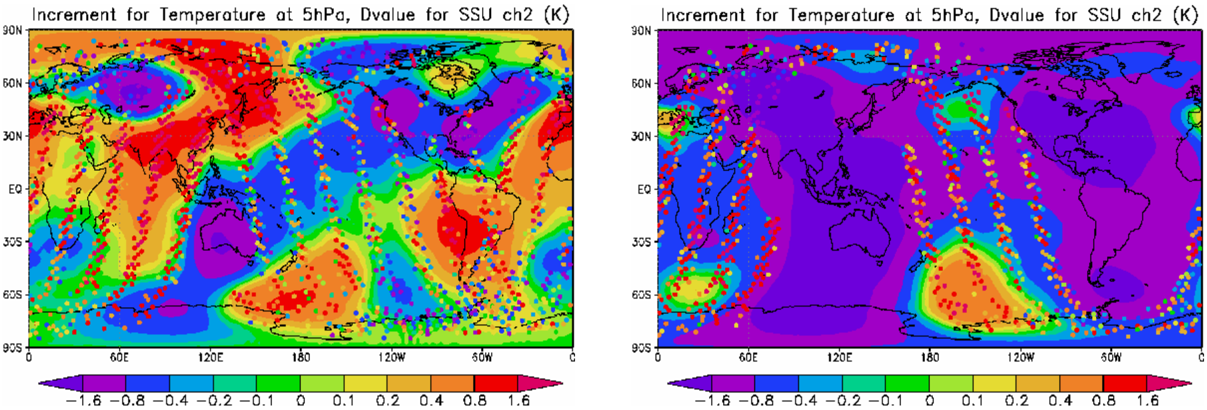


(a) 12hour time window (b) 6hour time window

Fig. 1 Increment for temperature at 5hPa (shades) and residual for SSU ch2 observation (colored circles)

(a) In the case of the 12 hour time window adapted, (b) in the case of the 6hour-time window.

Each one presents situation at 00UTC10JAN1991, hence each assimilation cycle is started from 00z10JAN1991.

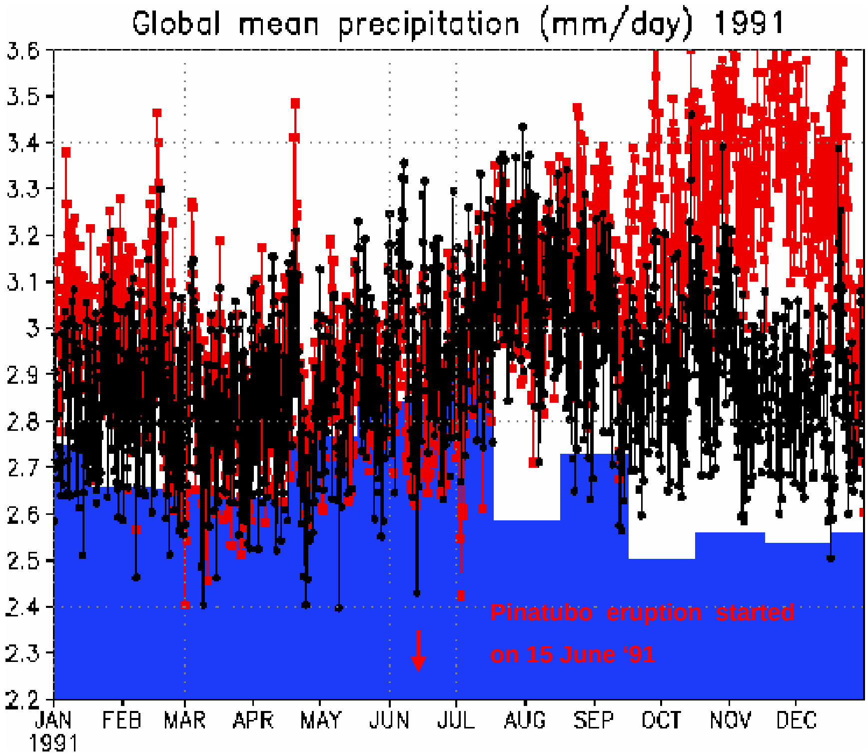
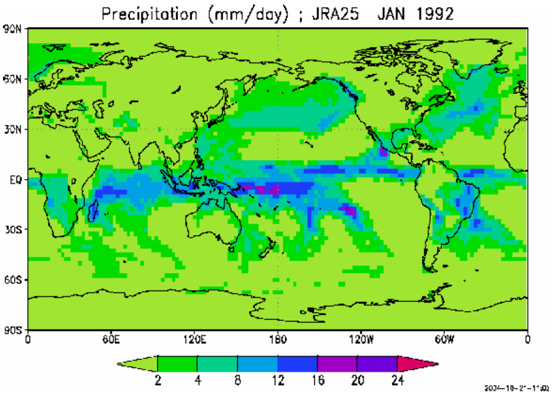
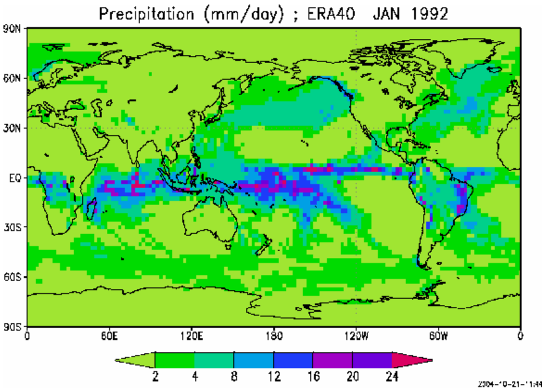


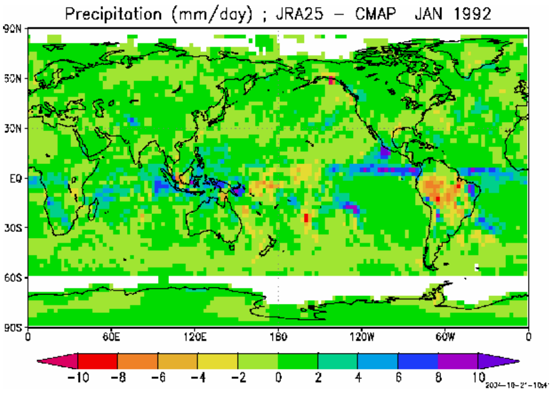
Fig. 2 Global mean Precipitation (mm/day) in1991. Black line shows JRA-25's, Red line ERA-40's, and Blue bars show CMAP's monthly mean value. After 15 June 1991 of the volcanic eruption of Mt. Pinatubo, an enormous amount of aerosol is assumed to have affected many types of remote-sensing observations. In the maximum periods of the aerosol contamination (September and October in 1991), the global mean precipitation of JRA-25 keeps similar seasonal change to CMAP's rather than ERA-40's.



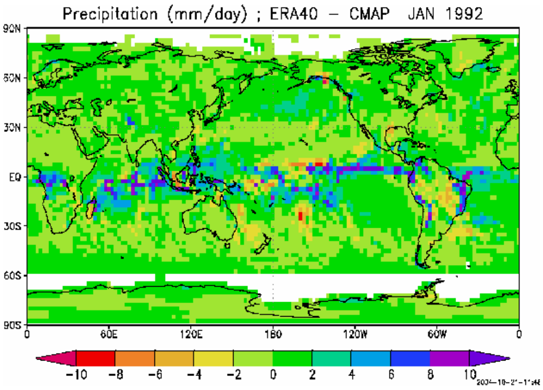
(a) Distribution of JRA-25



(b) Distribution of ERA-40



(c) Difference between JRA-25 and CMAP



(d) Difference between ERA-40 and CMAP

Fig3 Distribution of monthly mean precipitation (mm/day) in January 1991, (a) for JRA-25, (b) ERA-40's, Differences of monthly mean precipitation (c) between JRA-25 and CMAP, (d) between ERA-40 and CMAP.

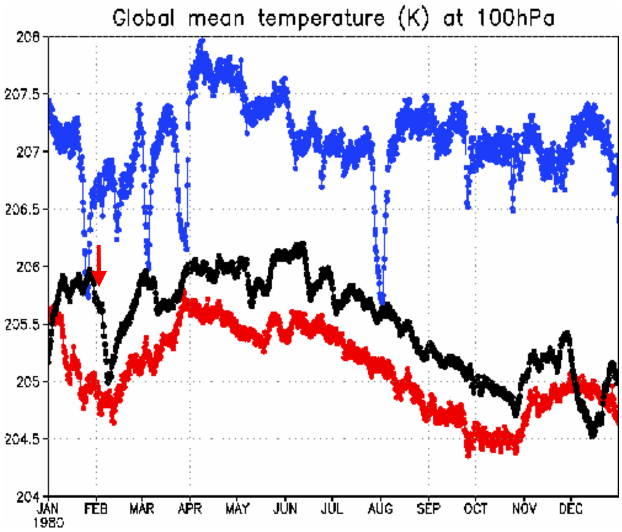


Fig.4 Global mean temperature at 100hPa in 1980. Black line shows JRA-25's, red line ERA-40's, and blue line NCEP/NCAR's reanalysis. In 1980, the use of TIROS-N HIRS/MSU observation ended until January, in February only NOAA-6 observation was available around this layer. At the beginning of February, inconsistency between observation of HIRS channel-3 and MSU channel-4 affects the time series of JRA-25 considerably.

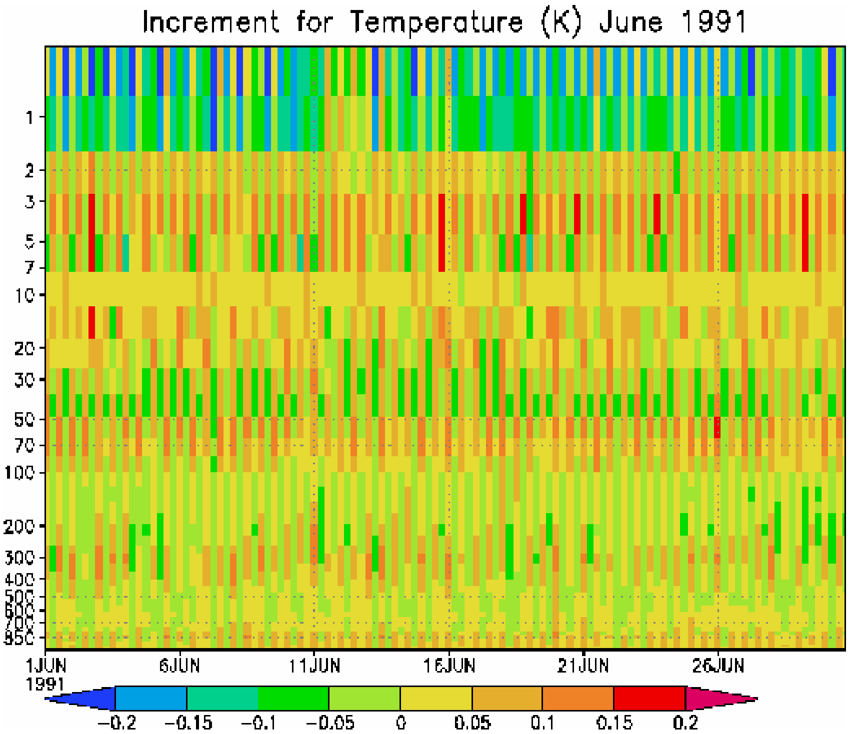


Fig.5 Global mean increment for temperature in June 1991.

Above 7hPa, these are large increments in magnitude recognized as the impacts of SSU observation. (Negative sign is dominant around 1.5 - 0.4hPa, positive one is around 7 - 1.5hPa.) Those might indicate forecast errors.